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Glass Color Standards for Maple Sirup*

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Previous official color standards for maple sirup, designated Light Amber, Medium Amber, and Dark Amber, were solutions of sugar caramel in glycerin standardized in terms of transmittance at 560 mμ. These solutions were not satisfactory because of instability of color and inconvenience of repeated preparation. Glass color standards were accordingly developed to match the chromaticities of fresh standard solutions in 31.5 mm depth. An improved color comparator was devised for use with the glass standards. The caramel-glycerin solutions and maple sirups were characterized spectrophotometrically and in terms of several one-dimensional color scales in use in the sugar industry. Complete specifications for the standard solutions and new glass standards are presented in the CIE system. Color tolerances were established in MacAdam units of chromaticity difference and a simple one-wavelength method of testing glasses for the production of duplicate standards was developed.

INTRODUCTION

FOR many years color has been an important factor in the grading and marketing of maple sirup. In 1910, Bryan[1] proposed a series of solutions of sugar caramel in glycerin as color standards for maple sirup. These standards had previously been used for grading cane sugar sirups.[2] They were contained in one-ounce glass vials and were numbered from 1 to 20. The concentration of caramel, made from "pure sugar" by an arbitrary procedure, was specified for each solution, increasing from zero for No. 1 to a maximum for No. 20. Balch[3] reported in 1930 that standard colors could not be duplicated by following Bryan's instructions when different lots of commercial granulated sugars were used for preparation of the caramel. He proposed transmittancy values at wavelength 560 mμ for the solutions in 1 cm thickness as primary specifications for the color standards, and adjusted the relative concentrations of the Bryan scale to effect a smooth relationship between transmittancy and Bryan number.[3,4]

In 1940[5] caramel-glycerin solutions prepared in accordance with Balch's spectrophotometric specifications for revised Bryan numbers 6, 8, and 10 became the official U. S. Department of Agriculture color standards for maple sirup. The standards were designated Light Amber, Medium Amber, and Dark Amber, respectively. A complete set for classifying the color of maple sirup included three standard solutions in cylindrical bottles of inside diameter about 28 mm, three turbid suspensions made by adding bentonite to three additional standard solutions (with the turbidity increasing from Light Amber to Dark Amber), empty bottles for samples of sirup, and a simple wooden comparator for holding three standards and two samples.

The classification of the color of maple sirup with these standards was essentially one-dimensional, based on the chromaticity aspect of the color. For example, a sirup was classified as Medium Amber if its color was perceptibly redder or more saturated than that of the Light Amber standard but not redder or more saturated than that of the Medium Amber standard. The turbid suspensions served the double purpose of facilitating the chromaticity comparison when the sirup to be classified was cloudy, and providing a guide for the limit of cloudiness permitted in each of the three grades. If the cloudiness of a sample exceeded these limits, the sirup was assigned a grade but was classified as sirup for reprocessing rather than as table maple sirup.

Caramel-glycerin standards had the advantage that they duplicated both the appearance and the spectral characteristics of maple sirups. Hence the viewing conditions, i.e., the light source and thickness of layer selected, were not critical. It has long been known, however, that such solutions fade slowly on exposure to light. For this reason the standard solutions were protected from light, except when in actual use, and were replaced each year. The unstable colors of these solutions, coupled with the inconvenience and potential errors of their batch-wise preparation, led the U. S. Department of Agriculture and the New York Department of Agriculture to initiate development of permanent glass color standards for maple sirup. The problem was to duplicate the colors of the existing standards, especially their chromaticities, with suitable amber glasses. The work was undertaken at this Laboratory in cooperation with the Processed Products Standardization and Inspection Branch, Agricultural Marketing Service. The availability of the new glass

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1 A. H. Bryan, Bur. Chem. Bulletin No. 134 (1910) (U. S. Dept. of Agriculture).

2 H. W. Wiley, Bur. Chem. Bulletin No. 93 (1905).

3 R. T. Balch, Ind. Eng. Chem. 22, 255 (1930).

4 C. A. Browne and F. W. Zerban, *Physical and Chemical Methods of Sugar Analysis* (John Wiley and Sons, Inc., New York, 1948), third edition, pp. 1172–1173.

5 "United States standards for table maple sirup" and "United States standards for maple sirup for reprocessing," Agricultural Marketing Service, U. S. Dept. of Agriculture, issued February 7, 1940.

Table I. Specifications for former caramel-glycerin color standards for maple sirup, and characterization of two sets of solutions I and II prepared for present investigation.

Prior specifications:	Note	Light amber			Medium amber			Dark amber		
Bryan number	a		6			8			10	
Transmittancy, %, 560 mμ, 1 cm	a		75.0			60.5			44.0	
Pfund color grader, mm	a,b		53.0			77.0			97.0	
Solutions, this investigation:		I	II	av	I	II	av	I	II	av
Transmittancy, %, 560 mμ, 1 cm	c	75.0	75.0	75.0	60.5	60.5	60.5	44.0	44.0	44.0
3.15 cm		40.7	40.5	40.6	20.4	20.8	20.6	7.54	7.56	7.55
Pfund color grader, mm	d	...	37.5	...	...	57.6	...	...	79.7	...
Absorbancy/cm 450 mμ, A_{450}/b	e	0.520	0.499	0.510	0.939	0.854	0.897	1.47	1.44	1.455
Absorbancy/cm, 420 mμ, A_{420}/b	f	0.777	0.771	0.774	1.40	1.32	1.36	(2.20)	2.23	2.22
$(A_{420}^{*}-2A^{*}_{720})/b$	g	0.737	0.737	0.737	1.33	1.26	1.30	(2.08)	2.13	2.11
Absorbancy ratio A_{600}/A_{660}	h	2.13	2.17	2.15	2.16	2.13	2.15	2.10	2.16	2.13
Slope or wavelength exponent, n	i	6.70	6.86	6.78	6.82	6.70	6.76	6.58	6.82	6.70
Chromaticity coordinates: x	j	0.4951	0.4961	0.4956	0.5554	0.5555	0.5555	0.5996	0.6058	0.6027
y		0.4492	0.4455	0.4474	0.4306	0.4282	0.4294	0.3967	0.3910	0.3939
Luminous transmittancy, %, T_c		39.3	39.2	39.3	21.5	22.2	21.9	9.97	10.54	10.26
Dominant Wavelength, mμ, Λ		582.4	582.7	582.6	588.2	588.5	588.4	594.8	595.9	595.4
Excitation Purity, %, P		84.8	84.6	84.7	96.4	95.8	96.1	99.1	99.4	99.3

[a] Balch, references 3 and 4.
[b] Balch, "corrected to master standard by means of calibration chart furnished by the manufacturer."
[c] Prepared to give transmittancy specified by Balch.
[d] Directly in terms of the primary wedge in standard instrument at Munsell Color Company, Baltimore (B.A.B. 1953).
[e] Color Index of maple sirup, Porter *et al.*[13]
[f] Color Index of filtered sugar solution when multiplied by $1000/c$, where c is concentration of sugar, g/ml. See page 276 of reference 14. For maple sirup $c=0.863$ g/ml.
[g] Compensated Color Index of sugar solutions when multiplied by $1000/c$, Gillett.[14,15]
[h] Q ratio, Peters and Phelps.[8,16]
[i] Slope of $\log A$ vs $\log\lambda$ curve, here calculated as $(1/0.049)\log(A_{600}/A_{660})$. See page 260 of reference 8.
[j] CIE data based on 1931 standard observer and Illuminant C, for 3.15 cm thickness of solutions (compensated for solvent).

color standards was announced[6] in 1950. It is the purpose of this paper to report details of this development and to present complete color specifications for the new standards.

CHARACTERIZATION OF MAPLE SIRUPS AND CARAMEL SOLUTIONS

Preliminary tests indicated that solutions prepared according to Balch's[3] single wavelength specification, from caramels of different source, may differ noticeably in color and spectral characteristics. Two sets of standard caramel-glycerin solutions were prepared for final use. Solutions I were prepared from commercial "Burnt Sugar Caramel Liquid"§; solutions II from a caramel concentrate made essentially by Bryan's method[1] by heating highly purified sucrose (NBS standard sample) for 30 min at 212°C in an oven. All solutions were prepared individually by dissolving a small amount of the caramel concentrate in warm glycerol (USP) with stirring until the specified transmittancy value was obtained when the solution was cooled to room temperature (25–28°C). The specified values are shown in Table I.

Before glass standards could be devised, it was obviously necessary to select a standard thickness for viewing the solutions and for the subsequent grading of maple sirups. It was found that a commercially available square 2-oz bottle having an average internal thickness of 3.15 cm (1.24 in.) met the requirements of a suitable container for practical grading. Precision optical cells of this internal thickness were constructed for spectrophotometric and color matching studies.

Spectrophotometric nomenclature in this paper will follow that used in the sugar industry.[7,8] Measurements of spectral transmittance were made on a General Electric recording spectrophotometer from 400 to 750 mμ and in some cases on a Beckman spectrophotometer from 380 to 400 mμ. Wavelength errors on the former instrument were judged not to exceed ± 0.5 mμ (at least from 440 to 700 mμ) by tests with a didymium filter[9] and with glass filters standardized for spectral transmittance by the National Bureau of Standards.[10] In these tests and in measuring the transmittancy of solutions and transmittance of glasses, values were read from the instrument dial rather than from continuous recordings. Whenever a value was below about 0.11, a more accurate transmittancy or transmittance was calculated from a measurement on a thinner layer of solution or glass. Color specifications based on the 1931 CIE standard observer[11] and Illuminant C for the solutions and glasses were calculated using the weighted ordinate method of integration at 10 mμ intervals from 380 to 760 mμ. CIE data for a number of maple sirups were evaluated less accurately from recorded transmittancy curves using a General Electric semiautomatic tristimulus integrator and the method of 30 selected ordinates.

[6] Brice, Turner, Southerland, and Bostwick, "Permanent glass color standards for maple sirup," Bur. Agric. Ind. Chem. AIC-260 (February, 1950) (Eastern Regional Research Laboratory); also published in Canner 110, No. 6, 10 (1950).

§ Obtained from S. Twitchell Company, Camden, New Jersey. Mention throughout this paper of specific commercial names or products does not imply recommendation or endorsement by the Department of Agriculture over other products of a similar nature not mentioned.

[7] Deitz, Pennington, and Hoffman, J. Research Natl. Bur. Standards 49, 365 (1952).

[8] M. L. Wolfrom, editor, *Advances in Carbohydrate Chemistry* (Academic Press, Inc., New York, 1954), Vol. 9, pp. 247–284. "Color and turbidity of sugar products," by R. W. Liggett and V. R. Deitz.

[9] H. J. Keegan and K. S. Gibson, J. Opt. Soc. Am. 34, 770 (1944).

[10] Gibson, Walker, and Brown, J. Opt. Soc. Am. 24, 58 (1934).

[11] D. B. Judd, J. Opt. Soc. Am. 23, 359 (1933); D. B. Judd, "Colorimetry," Natl. Bur. Standards Circ. 478 (March 1, 1950).

TABLE II. Attenuancy ratio and wavelength exponent (slope of logA^* *versus* logλ curve) for caramel-glycerin solutions and maple sirups of different origins.

	No. of samples	Attenuancy ratio A_{500}^*/A_{560}^* Av	Std. dev	Range	Wavelength exponent,[b] n Av	Std. dev.	Range
Caramel-glycerin solutions	5	2.12	±0.04	2.06–2.16	6.57	±0.20	6.37–6.82
Maple sirups, filtered	29	2.15	0.25	1.78–2.72	6.75	1.01	5.10–8.86
Maple sirups, unfiltered	19	2.06	0.33	1.57–2.72	6.27	1.41	3.98–8.85
Sugar liquors, filtered[a]	...	...	...	...	...	...	5.4 –8.5

[a] Liggett and Deitz.[8]
[b] Calculated as $\Delta \log A^*/\Delta \log\lambda$ for wavelengths 500 and 560 mμ.

The colors and transmitting properties of the caramel-glycerin solutions representing the previous color standards for maple sirup were characterized in a number of ways, as indicated in Table I, for purposes of comparison with other scales. These included several abridged or one-dimensional methods used in the sugar industry, in addition to Balch's transmittancy specification at 560 mμ. Scale readings for the nearest chromaticity match on the Pfund Color Grader,[12] a wedge comparator used for grading honey, are shown for solutions II directly in terms of the primary wedge (certified by Mrs. Blanche R. Bellamy, Munsell Color Company) in the standard instrument at Baltimore. The values are averages of 10 settings each, with a standard deviation of ± 0.4 mm (observer, B.A.B.). The discrepancies in comparison with Balch's data are too large to be accounted for by ordinary calibration errors and suggest that between 1930 and 1953 some major change had been made in the "standard" Pfund Color Grader or in its use. Shown next is absorbancy per cm at wavelength 450 mμ, used by Porter *et al.*[13] as an abridged "Color Index" in the heat processing of maple sirups, with correction to standard sirup density (0.863 g of solids, as sucrose, per ml). The average values for solutions I and II serve to locate approximately the grade boundaries on this one-dimensional scale for filtered sirups. A Color Index in use[14] for filtered sugar solutions is $1000\, A_{420}/bc$ where A_{420} is the absorbancy at 420 mμ, b the thickness of the solution and reference in cm, and c the concentration of sugar solids in g/ml. A widely used "Compensated Color Index" applicable to filtered or unfiltered sugar solutions, proposed by Gillett[14,15] to compensate for normal turbidity, is $(1000/bc)(A_{420}^* - A_{720}^*)$, where A^* is the attenuancy at the indicated wavelengths, in the nomenclature of Deitz[7,8] (attenuancy≡absorbancy in the absence of turbidity). Shown next in Table I is the absorbancy ratio A_{500}/A_{560} for wavelengths 500 and 560 mμ, a crude characterization of colorant identity since it is independent of thickness and colorant concentration. This was termed a "Q-ratio" by Peters and Phelps[8,16] and served to determine whether a given filtered sugar solution deviated from "normal" in spectral character. A similar characterization proposed by Liggett and Deitz,[8] and according to them more useful than a Q-ratio, is the slope of the approximately linear curve relating logarithm of absorbancy (or attenuancy) and logarithm of wavelength. These slopes or "wavelength exponents" were calculated for simplicity from the absorbancy values at 500 and 560 mμ since the plots for log$A$ *versus* logλ (Fig. 1) were not accurately linear. Finally in Table I complete CIE specifications are given for solutions I and II.

It is evident from Table I that although the solutions are identical with respect to Balch's specifications they differ perceptibly, especially the Dark Amber solutions, in other spectral characteristics and in final color (see Table III). The average values in Table I were taken to represent the previous color standards for maple sirup. For purposes of color specification, the CIE data furnish the only unambiguous characterization.

Data are assembled in Table II for attenuancy ratios and wavelength exponents for a number of maple sirups and caramel solutions of different origin to illustrate the variations in these quantities. The range in wavelength exponent for filtered maple sirups is essentially the same as that found by Liggett and Deitz[8] for filtered sugar liquors. The presence of turbidity obviously lowers both quantities. Curves relating absorbancy and wavelength, both on logarithmic scales, are plotted in Fig. 1 for caramel-glycerin solutions I and II and for five typical filtered maple sirups. Reference solutions for spectral data on all maple sirups were "colorless" sugar solutions of concentration 0.863 g/ml. The shapes of the curves depend only on the nature of the colorants and are independent of their concentration and the thickness of the solution. The curves indicate that caramel-glycerin solutions are good spectral matches for maple sirups and suggest that the principal colorant is similar for the two. Irregularities in the curves, and variations in the data of Tables I and II, indicate that minor variations in colorant composition exist both in maple sirups and in caramel solutions. This is further shown by the scattering of points in the CIE chromaticity diagram (Fig. 2). The colors of various caramel solutions and maple sirups

[12] E. L. Sechrist, "The color grading of honey," U. S. Dept. Agric., Dept. Circ. 364 (October, 1925).
[13] Porter, Buch, and Willits, Food Research 17, 475 (1952).
[14] P. Hornig, editor, *Principles of Sugar Technology* (Elsevier Publishing Company, New York, 1953), Chap. 8, "Color and colored nonsugars," by T. R. Gillett.
[15] Gillett, Meads, and Holven, Anal. Chem. 21, 1228 (1949).
[16] H. H. Peters and F. P. Phelps, Natl. Bur. Standards Technol. Papers 21, 261 (1927), No. 338.

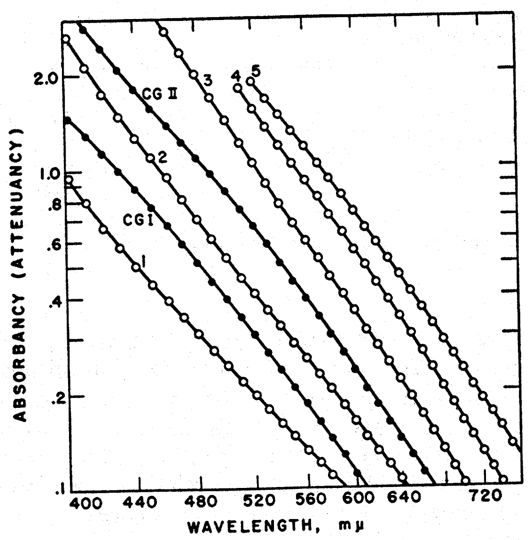


FIG. 1. Absorbancy, for thickness of 3.15 cm, *versus* wavelength (both on logarithmic scales) for caramel-glycerin solutions I (concentration less than for Light Amber) and II (Light Amber) measured relative to glycerin; and for typical filtered maple sirups (curves 1–5) measured relative to colorless sucrose solutions of concentration 0.863 g/ml.

are not strictly one-dimensional with respect to chromaticity. The situation is similar for sugar liquors (see p. 266 of reference 8). A good discussion of the colorants in sugar products is given by Liggett and Deitz.[8]

GLASS COLOR STANDARDS

A number of commercial amber glasses were examined for suitability as color standards for maple sirup by comparison with caramel-glycerin solutions I in 3.15 cm thickness. Glasses manufactured by L. J. Houze Convex Glass Company, Point Marion, Pennsylvania, were selected. These were available in a number of melts in the form of rolled sheets, only one side of which had to be ground and polished for adjustment to final color. Melts were selected by evaluating the chromaticity locus on the CIE diagram using three thicknesses of a glass which in stock thickness was redder than the solution to be matched. The thickness of glass required to give closest chromaticity match for a solution was estimated by interpolation on the x-, y- diagram. A final selection of melt and thickness was made visually with a Martens polarization photometer[17] equipped with a 6° circular field and a light source conforming closely to CIE Illuminant C (incandescent lamp operating at a color temperature near 2854°K plus Davis-Gibson filters).[11] The solution, in a precision cell of internal thickness 3.15 cm, was placed at one aperture of the photometer and the glass to be compared, plus glycerin in an equal cell, at the other aperture. Luminance differences were eliminated by adjusting the photometer so that only differences in chromaticity could be judged. No glasses were found which would closely match both hue and saturation simultaneously for the Light Amber and Medium Amber solutions. Adjustment of the glass thickness was made to effect a compromise match of hue and saturation, or nearest chromaticity match, for these solutions. Selection of a chromaticity match for the Dark Amber solution was easier, since the excitation purity of the solution and the glasses was near 100%. The glass stock used in this case was, however, not thick enough to effect a match, and two pieces in contact (not cemented) were used.

TABLE III. Chromaticity difference, in MacAdam units ΔS, between "standard" caramel-glycerin solutions I and II and master set of glass standards selected to match chromaticities of solutions I (3.15 cm of solution compensated by equal thickness of glycerin).

	Light amber	Medium amber	Dark amber
Solution I—glass standard	1.1	2.5	3.7
Solution II—glass standard	3.4	3.9	2.9
Average of I and II[a]—glass standard	2.3	3.2	3.3
Solution I—solution II	2.4	1.5	6.5

[a] Calculated from averaged x- and y-values, Table I.

TABLE IV. Specifications and colorimetric analysis for master set of glass color standards for maple sirup. CIE data are based on 1931 standard observer and Illuminant C.

		Light amber	Medium amber	Dark amber
Glass designation,[a] Amber No.		253–DK	66–LT	66–LT
Thickness, mm	b	1.78	4.01	7.54[b]
Tristimulus values$\times 10^{-3}$:	X	48.886	31.160	15.420
	Y	44.555	24.358	10.065
	Z	5.381	0.453	0.039
Chromaticity coordinates:	x	0.4947	0.5567	0.6041
	y	0.4509	0.4352	0.3943
Luminous transmittance, $\%T_c$		44.6	24.4	10.07
Dominant wavelength, mμ	λ	582.1	587.7	595.4
Excitation purity, %	P	85.5	98.0	99.7

[a] L. J. Houze Convex Glass Company designation.
[b] The Dark Amber standard comprises two separate components 4.04 and 3.41 mm thick (not cemented).

The final ground and polished glasses showing satisfactory chromaticity matches with solutions I for Illuminant C were adopted as the master set of glass color standards. Chromaticity differences in terms of MacAdam[18] units, calculated from the x- and y-chromaticity coordinates, appear in Table III. Solutions II had been prepared some time after selection of the master standards, and were found to be acceptable matches for the glasses. Fortunately the chromaticity of the dark amber glass was about midway between that of solutions I and II. The chromaticities of the glass standards differed from the average of those of the solutions by about 2 to 3 MacAdam units, which was considered acceptable for this work. These units express the ratio of a chromaticity difference to the standard deviation of matching at constant luminance by P. G.

[17] D. B. Judd, *Color in Business, Science, and Industry* (John Wiley and Sons, Inc., New York, 1952), p. 157.
[18] D. L. MacAdam, J. Opt. Soc. Am. 33, 18 (1943).

Nutting, Jr.[18] It was noted that the matches between the glasses and solutions were not as good for Illuminant A as for Illuminant C, indicating some metamerism.

Specifications and complete colorimetric analysis for the master set of glass color standards are given in Table IV. Chromaticity coordinates are plotted in Fig. 2 for the glasses and for caramel-glycerin solutions and typical maple sirups in 3.15 cm thicknesses. The average locus of chromaticities and scattering of points is similar to that found for other sugar products.[8] Spectral transmittance data for the master set of glass color standards are shown in Table V and plotted in Fig. 3. All glasses were finished to approximately 37-mm square.

COLOR TOLERANCES

Sufficient glass was purchased by the Department of Agriculture to assure a supply which would meet the estimated future requirements of governmental inspection agencies and the industry for duplicate sets of standards. Because of small variations of color within a given melt, it was necessary to establish color tolerances and a simple procedure for testing duplicate standards.

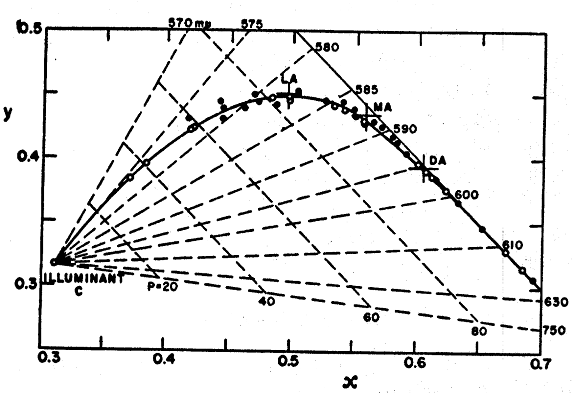


FIG. 2. CIE chromaticity diagram, showing coordinates for Light Amber, Medium Amber, and Dark Amber glass color standards (+); for caramel-glycerin solutions in 3.15 cm thickness (O); and for typical maple sirups, 3.15 cm (●).

Three series of glasses were selected or prepared, one series for each of the color standards, in which the individual pieces differed significantly in transmittance relative to that of the master standard at a selected wavelength. For convenience the wavelength selected was that showing a transmittance of 30.0% for the master standard. In general the transmittances of the glasses in a series ranged from about 28% to 32%, the extremes including glasses considered not acceptable as color matches for the master standards. From each series, glasses representing acceptable "light" and "dark" limits were selected by visual comparison of each glass with a master standard. The glasses (37 mm square) were held in close juxtaposition 12 to 18 inches from the eye, or were held as filters close to the eye in quick succession, using overcast sky as a source. These

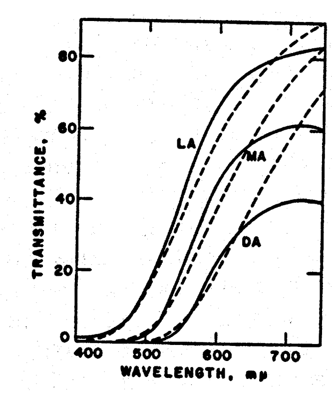
TABLE V. Spectral transmittance of glass color standards for maple sirup.

Wave-length, mμ	Light amber	Transmittance medium amber	Dark amber	Wave-length, mμ	Transmittance Light amber	Medium amber	Dark amber
380	0.018	0.00017	...	570	0.532	0.302	0.109
390	0.015	0.00010	...	580	0.583	0.356	0.148
400	0.012	0.00007	...	590	0.628	0.406	0.189
410	0.0112	0.00006	...	600	0.666	0.449	0.227
420	0.0117	0.00007	...	610	0.697	0.484	0.260
430	0.0141	0.00010	...	620	0.721	0.511	0.288
440	0.0191	0.00021	...	630	0.742	0.532	0.311
450	0.0273	0.00046	...	640	0.758	0.550	0.330
460	0.0400	0.0011	...	650	0.772	0.565	0.346
470	0.0570	0.0023	0.00002	660	0.783	0.577	0.361
480	0.0806	0.0054	0.00007	670	0.792	0.588	0.374
490	0.111	0.0111	0.00026	680	0.801	0.597	0.384
500	0.148	0.0210	0.00083	690	0.808	0.605	0.393
510	0.193	0.0374	0.0024	700	0.814	0.611	0.399
520	0.243	0.0620	0.0060	710	0.818	0.613	0.403
530	0.299	0.0962	0.0132	720	0.822	0.614	0.404
540	0.357	0.138	0.0262	730	0.825	0.613	0.403
550	0.418	0.190	0.0467	740	0.827	0.610	0.401
560	0.476	0.244	0.0746	750	0.828	0.606	0.395

conditions are comparable with those preferred for practical color classification of maple sirup.

Spectral transmittances of all glasses in the series were measured and tristimulus values and chromaticity coordinates calculated for Illuminant C. The chromaticity difference between each glass and the corresponding master standard was calculated in terms of MacAdam units[18] (ΔS) and in terms of the distance between points on the x-, y-chromaticity diagram (ΔC). Color differences in NBS units (ΔE) were calculated from the tristimulus data by the Adams-Nickerson formula[19] with $f=50$. The glasses selected to represent approximate acceptable limits showed nearly constant differences on all three scales for the three color standards, with ΔS ranging from 2.0 to 2.7 MacAdam units, ΔC from 0.0027 to 0.0035, and ΔE 1.3 to 2.1 NBS units. A chromaticity tolerance of ± 2.5 MacAdam units, which ordinarily corresponds to a just-noticeable difference, was adopted. This tolerance was converted to acceptable one-wavelength transmittance units by plotting ΔS *versus* T_λ from 28% to 32% for all three series. The data are shown in Table VI. Tolerances in

FIG. 3. Transmittancy curves for previous color standards for maple sirup, represented by caramel-glycerin solutions I, 3.15 cm, relative to glycerin; and transmittance curves of glass color standards selected to match the chromaticities of the solutions. Solutions - - -. Glasses ———.



[19] See reference 17, pp. 265–267, 352–357.

TABLE VI. Color tolerances adopted for testing and producing duplicate glass standards, based on $\Delta S = \pm 2.5$ MacAdam units of chromaticity difference.

		Light amber	Medium amber	Dark amber
Test wavelength (approx), $m\mu$	λ	530	569	569[a],561[b],625[c]
Transmittance, master standard, near λ, %	T_s	30.0	30.0	30.0
Tolerances for duplicate standards:				
Units of transmittance near λ	ΔT	±1.1	±1.1	±1.0
MacAdam units, chromaticity diff.[d]	ΔS	2.5	2.5	2.5
Adams-Nickerson units, color diff.[e]	ΔE	1.6	1.5	2.0
CIE chromaticity difference[f]	ΔC	3.4	3.3	3.3
Units of glass thickness, mm	Δb	0.06	0.14	0.22
	$100\Delta b/b_s$	3.3	3.3	3.0

[a-c] For testing thick component (4.04 mm), thin component (3.41 mm), and finished combination, respectively.
[d] $\Delta S = [g_{11}(\Delta x)^2 + 2g_{12}\Delta x\Delta y + g_{22}(\Delta y)^2]^{\frac{1}{2}}$
[e] $\Delta E = 50\{(0.23V_Y)^2 + [\Delta(V_X - V_Y)]^2 + [0.4\Delta(V_Z - V_Y)]^2\}^{\frac{1}{2}}$
[f] $\Delta C = 1000[(\Delta x)^2 + (\Delta y)^2]^{\frac{1}{2}}$

terms of the other units were obtained from plots of ΔE and ΔC *versus* T_λ after the limits for transmittance had been adjusted to correspond to ±2.5 MacAdam units. All plots were linear. Corresponding tolerances for thickness of glass were calculated from the transmittance limits and the actual thickness of the master standards (Table IV). It is apparent from Table VI that the tolerances for transmittance units would be practically the same whether they were based on ±2.5 MacAdam units, ±1.6 NBS units (from Adams-Nickerson formula), or ±0.0033 unit of length on the x-, y-chromaticity diagram. The constancy of the latter for all three colors (Table VI) is largely coincidental and would not generally be expected in different regions of the CIE diagram.

The measurement of transmittance of finished glasses at one wavelength, with established tolerances in these units (Table VI), furnishes a rapid method of testing duplicate standards for acceptability, and can be done by technicians inexperienced in color matching. The method is differential and hence essentially free of errors of wavelength and photometric scale. (For some types of spectrophotometers the measurements and data would be more conveniently expressed in terms of transmittance relative to that of the master standard.) The technique was extended also to the testing of stock glasses prior to grinding and polishing in order to reduce the number of rejections. Stock glasses were cut into 37-mm squares and placed in the spectrophotometer at the wavelength required to show 30.0% transmittance for the master standard. The thickness and transmittance of each piece was recorded. The thickness required to give a transmittance of 30.0%, and hence standard color, was determined by reference to a calculated curve relating transmittance (10 to 32%) to relative thickness (absorbancy ratio). The curve was nearly linear and could be used for all the standards and components indicated in Table VI. For example, a glass with a transmittance 11.0% would require that its measured thickness be reduced by a factor 0.526 (i.e., absorbance ratio, corrected for reflection losses) in order to have a standard transmittance of 30.0%. Because of variations within the melt, the calculated thickness would not necessarily be the same as the thicknesses of the master standards indicated in Table IV. Stock glasses tested in this way were placed in groups having nearly the same predicted thickness. Grinding and polishing was then performed batch-wise on these groups, and very few rejections resulted unless thickness tolerances were exceeded. This procedure was less important with the dark amber components since light and dark pieces could usually be mated to give an acceptable standard by testing the finished glasses in combination near 625 $m\mu$ (Table VI).

COLOR COMPARATOR

A simple color comparator was devised for use in classifying maple sirup for color with the glass standards This was a rectangular, black metal box of dimensions approximately 8 by 2 by 3 in., divided by thin partitions into five square compartments, and equipped with five windows 30 mm square and 9 mm apart in front and in back (Fig. 4). The glasses are mounted behind the front windows of compartments 1, 3, and 5. Square bottles filled with clear glycerin-water solutions (approximately equal parts by volume) are placed in the compartments behind the standards to serve as nonfreezing colorless "blanks," and to duplicate the appearance of a filled bottle of maple sirup when the observer looks through a standard aperture. A square bottle filled with maple sirup to be classified is placed in compartment 2 or 4 and compared with adjacent standards using a natural

FIG. 4. Color comparator for grading maple sirup, showing bottles with clear blanks behind the glass standards, the three cloudy suspensions A, B, and C; and a sample of maple sirup to be classified.

or artificial daylight source, holding the comparator 12 to 18 inches from the eye.

Three turbid suspensions designated Cloudy A, Cloudy B, and Cloudy C are provided in square bottles as accessories to aid in classifying cloudy maple sirups. These are suspensions of diatomaceous earth (Johns-Manville Hyflo Super-Cel) in concentrations 100, 200, and 400 milligrams per liter in glycerin-water solutions similar to the clear blanks. Most of the turbidity of maple sirup is due to incomplete removal of insoluble calcium malate by crude filtration of the sirup after processing. When a cloudy maple sirup is to be graded, the clear blanks are replaced by the suspensions, which may be switched from compartment to compartment until a final comparison is made between the sample and a glass standard (backed by a cloudy suspension) at about the same level of luminance. Tests with the polarization photometer indicated that superposing a cloudy suspension on a glass standard does not perceptibly disturb a chromaticity match, although the suspensions are slightly selective in spectral transmittance. Suspensions of bentonite are less satisfactory in this respect; they are more selective in spectral transmittance and produce a noticeable shift in chromaticity toward the red when superposed on a glass standard (especially Light Amber).

The sample bottles adopted are made by Hazel Atlas Glass Company as No. 2653 French square tablet bottles 1.5 in. square and 2+ oz capacity. Measurements on some 30 bottles indicated an average internal thickness of 31.5 mm, with a standard deviation of ± 0.4 mm. They are not of good optical quality of course but are convenient, inexpensive, and adequate for routine visual color classification. Errors can occur only when the chromaticity of a sirup is near that of a standard. More precise classification, or refereeing a disputed color, can be done in the laboratory using optical cells of 31.5-mm internal thickness, the master glass standards, and the polarization photometer with CIE Illuminant C.

The new comparator is superior to arrangements previously used for classifying the color of maple sirup. Features contributing to improved grading are: the relatively greater thickness of the sirup layer viewed, resulting in a wider spacing of standards on a chromaticity scale; the square shape of the sample container, providing a field of view of uniform thickness and color not possible with cylindrical containers; large square viewing apertures (30×30 mm) and a narrower dividing line (9 mm) between standard and sample apertures; and finally, color standards that are not subject to change under conditions of use.

As stated earlier in the paper, color classification of maple sirup is done on the basis of chromaticity only, the glass standards furnishing boundary points for the grade intervals on a one-dimensional scale.

The glass standards became the official U. S. Department of Agriculture color standards for maple sirup in 1950 and have been adopted also by New York and Vermont. The grading sets are available commercially from the Phoenix Precision Instrument Company, Philadelphia. Some 300 sets are now in use by producers and users of maple sirup as well as by governmental inspection agencies.